Industry Canada | Industrie Canada

Canada Business Corporations Act | Loi canadienne sur les sociétés par actions

I HEREBY CERTIFY THAT THE ATTACHED IS A TRUE COPY OF THE DOCUMENT MAINTAINED IN THE RECORDS OF THE DIRECTOR.

JE CERTIFIE, PAR LES PRÉSENTES, QUE LE DOCUMENT CI-JOINT EST UNE COPIE EXACTE D'UN DOCUMENT CONTENU DANS LES LIVRES TENUS PAR LE DIRECTEUR.

Deputy Director - Directeur adjoint

Date

Canada Business Corporation Act
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Loi canadienne sur les sociétés par actions

Canada

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Certificate of Amendment | **Certificat de modification**

Canada Business Corporations Act | **Loi canadienne sur les sociétés par actions**

TORR CANADA INC. | 290716-0

Name of corporation-Dénomination de la société | Corporation number-Numéro de la société

I hereby certify that the articles of the above-named corporation were amended:

Je certifie que les statuts de la société susmentionnée ont été modifiés:

☐ a) under section 13 of the *Canada Business Corporations Act* in accordance with the attached notice;

a) en vertu de l'article 13 de la *Loi canadienne sur les sociétés par actions*, conformément à l'avis ci-joint;

☐ b) under section 27 of the *Canada Business Corporations Act* as set out in the attached articles of amendment designating a series of shares;

b) en vertu de l'article 27 de la *Loi canadienne sur les sociétés par actions*, tel qu'il est indiqué dans les clauses modificatrices ci-jointes désignant une série d'actions;

☑ c) under section 179 of the *Canada Business Corporations Act* as set out in the attached articles of amendment;

c) en vertu de l'article 179 de la *Loi canadienne sur les sociétés par actions*, tel qu'il est indiqué dans les clauses modificatrices ci-jointes;

☐ d) under section 191 of the *Canada Business Corporations Act* as set out in the attached articles of reorganization;

d) en vertu de l'article 191 de la *Loi canadienne sur les sociétés par actions*, tel qu'il est indiqué dans les clauses de réorganisation ci-jointes;

Richard G. Shaw
Director - Directeur

November 4, 2005 / le 4 novembre 2005
Date of Amendment - Date de modification

Canada

Industry Canada Industrie Canada
Canada Business Corporations Act Loi canadienne sur les sociétés par actions

FORM 4
ARTICLES OF AMENDMENT
(SECTIONS 27 OR 177)

FORMULAIRE 4
CLAUSES MODIFICATRICES
(ARTICLES 27 OU 177)

ENVIRONMENTAL APPLIED RESEARCH TECHNOLOGY HOUSE - EARTH (CANADA) CORPORATION MAISON DE RECHERCHE APPLIQUÉE ET DE TECHNOLOGIE EN MATIÈRE ENVIRONNEMENTALE - CORPORATION EARTH (CANADA)	2807160

1 - The articles of the above-named corporation are amended as follows: Les statuts de la société mentionnée ci-dessus sont modifiés de la façon suivante :

Section 1 of the articles of incorporation be and the same is hereby deleted and replaced by the following:

1 - Name of the Corporation

TORR CANADA INC.

BATCH
2005 -11- 07
12:00

Signature	Printed Name - Nom en lettres moulées	4 - Capacity of - En qualité de	5 - Tel. No. - N° de tél.
	JACQUES L. DROUIN	Chief Financial Officer & Secretary	(514) 522-5550

FOR DEPARTMENTAL USE ONLY - À L'USAGE DU MINISTÈRE SEULEMENT

IC 3069 (2001/06)

Canada

TORR Canada inc.
1155, rue Wellington
Montréal, QC
H3C 1V9
Tél : (514) 522-5550
Téléc : (514) 522-2643

Anciennement La Corporation EARTH (Canada)

Sujet : Changement de raison sociale / Name Change

Veuillez prendre note que depuis le 4 novembre 2005, tel que voté par les actionnaires à l'assemblée générale, Environmental Applied Research Technology House appelé La Corporation EARTH (Canada) situé au 1155, rue Wellington, Montréal (Québec) H3C 1V9 a officiellement changé sa raison sociale pour **TORR Canada inc.** Ce changement de raison sociale nous permettra de mieux mettre en évidence notre identité corporative en tant qu'entreprise dédiée à devenir un chef de file mondial dans le développement des technologies de pointe pour remédier aux problèmes des hydrocarbures que l'on retrouve sur les sites de traitement de l'eau de production d'huile et de gaz à travers le monde.

À cet effet, nous vous demandons que toutes communications soient adressées à :

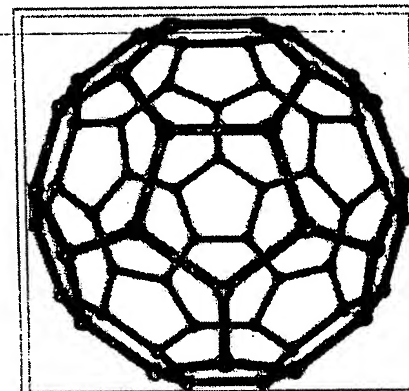
Please be advised that as of November 4th 2005, as voted on by the shareholders at the Annual General Meeting, Environmental Applied Research Technology House known as EARTH (Canada) Corporation, located at 1155 Wellington Street, Montreal Quebec H3C 1V9, has officially changed its corporate name to **TORR Canada Inc.** The corporate name change will allow us to better clarify the current identity of the Corporation as a focused enterprise dedicated to achieving its mission of becoming a world leader in the development of cutting edge technologies for hydrocarbon remediation worldwide.

To that effect, we request that all future correspondence with us be addressed to:

TORR Canada inc.
1155, rue Wellington
Montréal (Quebec)
H3C 1V9
Tél. : (514) 522-5550
Téléc. : (514) 522-2643
Courriel : info@torrcanada.com
Internet : www.torrcanada.com

Nanotechnology

From Wikipedia, the free encyclopedia



Buckminsterfullerene C_{60}, also known as the buckyball, is the simplest of the carbon structures known as fullerenes. Members of the fullerene family are a major subject of research falling under the nanotechnology umbrella.

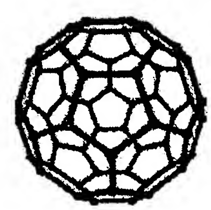
Nanotechnology is a field of applied science and technology covering a broad range of topics. The main unifying theme is the control of matter on a scale smaller than 1 micrometer, normally between 1-100 nanometers, as well as the fabrication of devices on this same length scale. It is a highly multidisciplinary field, drawing from fields such as colloidal science, device physics, and supramolecular chemistry. Much speculation exists as to what new science and technology might result from these lines of research. Some view nanotechnology as a marketing term that describes pre-existing lines of research applied to the sub-micron size scale.

Despite the apparent simplicity of this definition, nanotechnology actually encompasses diverse lines of inquiry. Nanotechnology cuts across many disciplines, including colloidal science, chemistry, applied physics, materials science, and even mechanical and electrical engineering. It could variously be seen as an extension of existing sciences into the nanoscale, or as a recasting of existing sciences using a newer, more modern term. Two main approaches are used in nanotechnology: one is a "bottom-up" approach where materials and devices are built from molecular components which assemble themselves chemically using principles of molecular recognition; the other being a "top-down" approach where nano-objects are constructed from larger entities without atomic-level control.

The impetus for nanotechnology has stemmed from a renewed interest in colloidal science, coupled with a new generation of analytical tools such as the atomic force microscope (AFM) and the scanning tunneling microscope (STM). Combined with refined processes such as electron beam lithography and molecular beam epitaxy, these instruments allow the deliberate manipulation of nanostructures, and in turn led to the observation of novel phenomena. The manufacture of polymers based on molecular structure, or the design of computer chip layouts based on surface science are examples of nanotechnology in modern use. Despite the great promise of numerous nanotechnologies such as quantum dots and nanotubes, real applications that have moved out of the lab and into the marketplace have mainly utilized the advantages of colloidal nanoparticles in bulk form, such as suntan lotion, cosmetics, protective coatings, and stain resistant clothing.

Contents

Nanotechnology



Topics

• History • Implications• Applications • Organizations • Popular culture • List of topics

Subfields and related fields

• Nanomedicine• Molecular self-assembly • Molecular electronics• Scanning probe microscopy• Nanolithography• Molecular nanotechnology

Nanomaterial

Nanomaterials • Fullerene • Carbon nanotubes • Fullerene chemistry • Applications • Popular culture • Timeline • Carbon allotropes • • Nanoparticles • Quantum dots • Colloidal gold • Colloidal silver

See Also

Origins

The first distinguishing concepts in nanotechnology (but predating use of that name) was in "There's Plenty of Room at the Bottom," a talk given by physicist Richard Feynman at an American Physical Society meeting at Caltech on December 29, 1959. Feynman described a process by which the ability to manipulate individual atoms and molecules might be developed, using one set of precise tools to build and operate another proportionally smaller set, so on down to the needed scale. In the course of this, he noted, scaling issues would arise from the changing magnitude of various physical phenomena: gravity would become less important, surface tension and Van der Waals attraction would become more important, etc. This basic idea appears feasible, and exponential assembly enhances it with parallelism to produce a useful quantity of end products.

The term "nanotechnology" was defined by Tokyo Science University Professor Norio Taniguchi in a 1974 paper (N. Taniguchi, "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974.) as follows: "'Nano-technology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or one molecule." In the 1980s the basic idea of this definition was explored in much more depth by Dr. K. Eric Drexler, who promoted the technological significance of nano-scale phenomena and devices through speeches and the books Engines of Creation: The Coming Era of Nanotechnology and *Nanosystems: Molecular Machinery, Manufacturing, and Computation,* (ISBN 0-471-57518-6), and so the term acquired its current sense.

Nanotechnology and nanoscience got started in the early 1980s with two major developments; the birth of cluster science and the invention of the scanning tunneling microscope (STM). This development led to the discovery of fullerenes in 1986 and carbon nanotubes a few years later. In another development, the synthesis and properties of semiconductor nanocrystals was studied. This led to a fast increasing number of metal oxide nanoparticles of quantum dots. The atomic force microscope was invented five years after the STM was invented. The AFM uses atomic force to see the atoms.

Fundamental concepts

One nanometer (nm) is one billionth, or 10^{-9} of a meter. For comparison, typical carbon-carbon bond

lengths, or the spacing between these atoms in a molecule, are in the range .12-.15 nm, and a DNA double-helix has a diameter around 2 nm. On the other hand, the smallest cellular lifeforms, the bacteria of the genus Mycoplasma, are around 200 nm in length.

Larger to smaller: a materials perspective

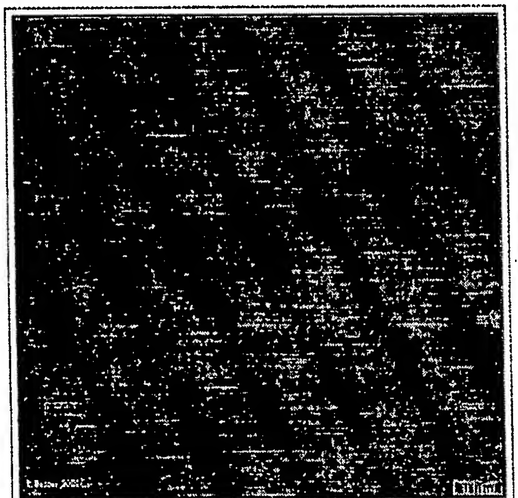


Image of reconstruction on a clean Au (100) surface, as visualized using scanning tunneling microscopy. The individual atoms composing the surface are visible.

A unique aspect of nanotechnology is the vastly increased ratio of surface area to volume present in many nanoscale materials which opens new possibilities in surface-based science, such as catalysis. A number of physical phenomena become noticeably pronounced as the size of the system decreases. These include statistical mechanical effects, as well as quantum mechanical effects, for example the "quantum size effect" where the electronic properties of solids are altered with great reductions in particle size. This effect does not come into play by going from macro to micro dimensions. However, it becomes dominant when the nanometer size range is reached. Additionally, a number of physical properties change when compared to macroscopic systems. One example is the increase in surface area to volume of materials. This catalytic activity also opens potential risks in their interaction with biomaterials.

Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale, enabling unique applications. For instance, opaque substances become transparent (copper); inert materials become catalysts (platinum); stable materials turn combustible (aluminum); solids turn into liquids at room temperature (gold); insulators become conductors (silicon). A material such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these unique quantum and surface phenomena that matter exhibits at the nanoscale.

Simple to complex: a molecular perspective

Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to produce a wide variety of useful chemicals such as pharmaceuticals or commercial polymers. This ability raises the question of extending this kind of control to the next-larger level, seeking methods to assemble these single molecules into supramolecular assemblies consisting of many molecules arranged in a well defined manner.

These approaches utilize the concepts of molecular self-assembly and/or supramolecular chemistry to automatically arrange themselves into some useful conformation through a bottom-up approach. The concept of molecular recognition is especially important: molecules can be designed so that a specific conformation or arrangement is favored due to non-covalent intermolecular forces. The Watson-Crick basepairing rules are a direct result of this, as is the specificity of an enzyme being targeted to a single substrate, or the specific folding of the protein itself. Thus, two or more components can be designed to be complementary and mutually attractive so that they make a more complex and useful whole.

Such bottom-up approaches should, broadly speaking, be able to produce devices in parallel and much cheaper than top-down methods, but could potentially be overwhelmed as the size and complexity of the desired assembly increases. Most useful structures require complex and thermodynamically unlikely arrangements of atoms. Nevertheless, there are many examples of self-assembly based on molecular recognition in biology, most notably Watson-Crick basepairing and enzyme-substrate interactions. The challenge for nanotechnology is whether these principles can be used to engineer novel constructs in addition to natural ones.

Molecular Nanotechnology: a long-term view

Molecular nanotechnology, sometimes called molecular manufacturing, is a term given to the concept of engineered nanosystems (nanoscale machines) operating on the molecular scale. It is especially associated with the concept of a molecular assembler, a machine that can produce a desired structure or device atom-by-atom using the principles of mechanosynthesis. Manufacturing in the context of productive nanosystems is not related to, and should be clearly distinguished from, the conventional technologies used to manufacture nanomaterials such as carbon nanotubes and nanoparticles.

When the term "nanotechnology" was independently coined and popularized by Eric Drexler (who at the time was unaware of an earlier usage by Norio Taniguchi) it referred to a future manufacturing technology based on molecular machine systems. The premise was that molecular-scale biological analogies of traditional machine components demonstrated that molecular machines were possible: by the countless examples found in biology, it is known that billions of years of evolutionary feedback can produce sophisticated, stochastically optimized biological machines. It is hoped that developments in nanotechnology will make possible their construction by some other means, perhaps using biomimetic principles. However, Drexler and other researchers have proposed that advanced nanotechnology, although perhaps initially implemented by biomimetic means, ultimately could be based on mechanical engineering principles, namely, a manufacturing technology based on the mechanical functionality of these components (such as gears, bearings, motors, and structural members) that would enable programmable, positional assembly to atomic specification (PNAS-1981). The physics and engineering performance of exemplar designs were analyzed in Drexler's book Nanosystems. But Drexler's analysis is very qualitative and does not address very pressing issues, such as the "fat fingers" and "Sticky fingers" problems. In general it is very difficult to assemble devices on the atomic scale, as all one has to position atoms are other atoms of comparable size and stickyness.

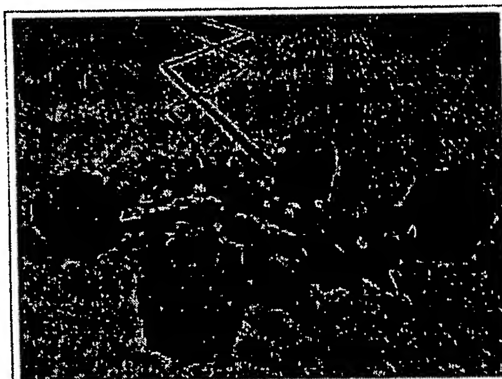
Another view, put forth by Carlo Montemagno, is that future nanosystems will be hybrids of silicon technology and biological molecular machines. Yet another view, put forward by the late Richard Smalley, is that mechanosynthesis is impossible due to the difficulties in mechanically manipulating individual molecules. This led to an exchange of letters in the ACS publication Chemical & Engineering News in 2003.

Though biology clearly demonstrates that molecular machine systems are possible, non-biological molecular machines are today only in their infancy. Leaders in research on non-biological molecular machines are Dr. Alex Zettl and his colleagues at Lawrence Berkeley Laboratories and UC Berkeley. They have constructed at least three distinct molecular devices whose motion is controlled from the desktop with changing voltage: a nanotube nanomotor, a molecular actuator, and a nanoelectromechanical relaxation oscillator. An experiment indicating that positional molecular assembly is possible was performed by Ho and Lee at Cornell University in 1999. They used a scanning

tunneling microscope to move an individual carbon monoxide molecule (CO) to an individual iron atom (Fe) sitting on a flat silver crystal, and chemically bound the CO to the Fe by applying a voltage.

Current research

As nanotechnology is a very broad term, there are many disparate but sometimes overlapping subfields that could fall under its umbrella. The following avenues of research could be considered subfields of nanotechnology. Note that these categories are fairly nebulous and a single subfield may overlap many of them, especially as the field of nanotechnology continues to mature.

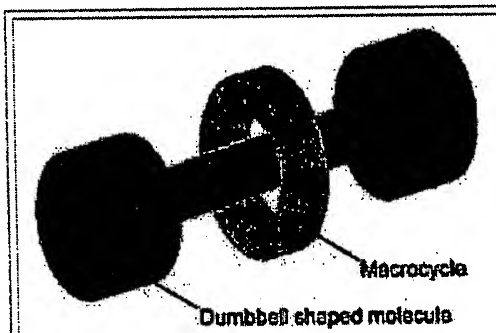


Space-filling model of the nanocar on a surface, using fullerenes as wheels.

Nanomaterials

This includes subfields which develop or study materials having unique properties arising from their nanoscale dimensions.

- **Colloid science** has given rise to many materials which may be useful in nanotechnology, such as carbon nanotubes and other fullerenes, and various nanoparticles and nanorods.
- Nanoscale materials can also be used for **bulk applications**; most present commercial applications of nanotechnology are of this flavor.
- Headway has been made in using these materials for medical applications; see **Nanomedicine**.



Graphical representation of a rotaxane, useful as a molecular switch.

Bottom-up approaches

These seek to arrange smaller components into more complex assemblies.

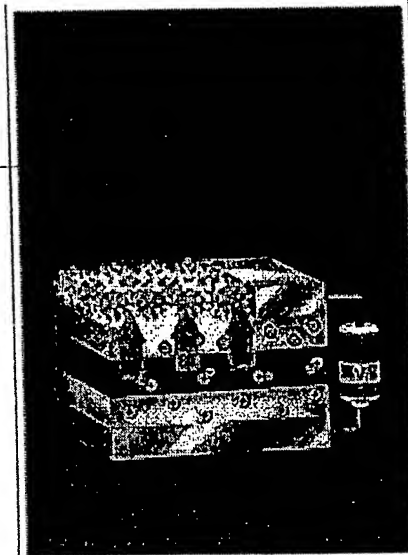
- **DNA Nanotechnology** utilizes the specificity of Watson-Crick basepairing to construct well-defined structures out of DNA and other nucleic acids.
- More generally, **molecular self-assembly** seeks to use concepts of supramolecular chemistry, and molecular recognition in particular, to cause single-molecule components to automatically arrange themselves into some useful conformation.

Top-down approaches

These seek to create smaller devices by using larger ones to direct their assembly.

- Many technologies descended from conventional **solid-state silicon methods** for fabricating microprocessors are now capable of creating features smaller than 100 nm, falling under the definition of nanotechnology. Giant magnetoresistance-based hard drives already on the market fit this description, [2] as do atomic layer deposition (ALD) techniques.

- Solid-state techniques can also be used to create devices known as **nanoelectromechanical systems** or NEMS, which are related to microelectromechanical systems or MEMS.
- Atomic force microscope tips can be used as a nanoscale "write head" to deposit a chemical on a surface in a desired pattern in a process called **dip pen nanolithography**. This fits into the larger subfield of nanolithography.



This device transfers energy from nano-thin layers of quantum wells to nanocrystals above them, causing the nanocrystals to emit visible light. [1]

Functional approaches

These seek to develop components of a desired functionality without regard to how they might be assembled.

- **Molecular electronics** seeks to develop molecules with useful electronic properties. These could then be used as single-molecule components in a nanoelectronic device. For an example see rotaxane.
- Synthetic chemical methods can also be used to create **synthetic molecular motors**, such as in a so-called nanocar.

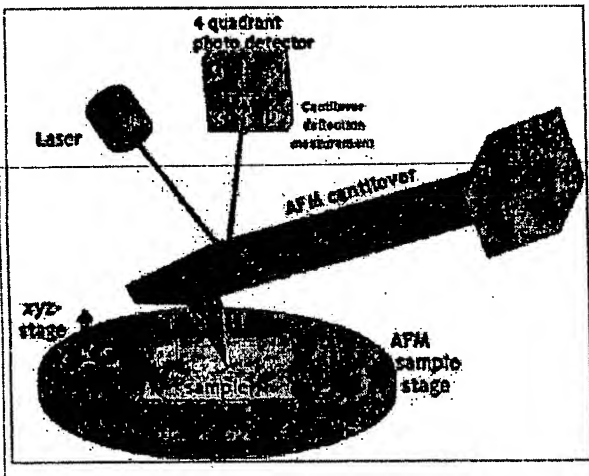
Speculative

These subfields seek to anticipate what inventions nanotechnology might yield, or attempt to propose an agenda along which inquiry might progress. These often take a big-picture view of nanotechnology, with more emphasis on its societal implications than the details of how such inventions could actually be created.

- **Molecular nanotechnology** is a proposed approach which involves manipulating single molecules in finely controlled, deterministic ways. This is more theoretical than the other subfields and is beyond current capabilities.
- **Nanorobotics** centers on self-sufficient machines of some functionality operating at the nanoscale. There are hopes for applying nanorobots in medicine [1][2][3], while it might not be easy to do such a thing because of several drawbacks of such devices [4][5].
- **Programmable matter** based on artificial atoms seeks to design materials whose properties can be easily and reversibly externally controlled.
- Due to the popularity and media exposure of the term nanotechnology, the words **picotechnology** and **femtotechnology** have been coined in analogy to it, although these are only used rarely and informally.

Tools and techniques

Nanotechnological techniques include those used for fabrication of nanowires, those used in semiconductor fabrication such as deep ultraviolet lithography, electron beam lithography, focused ion beam machining, nanoimprint lithography, atomic layer deposition, and molecular vapor deposition, and further including molecular self-assembly techniques such as those employing di-block copolymers. However, all of these techniques preceded the nanotech era, and are extensions in the development of scientific advancements rather than techniques which were devised with the sole purpose of creating



Typical AFM setup. A microfabricated cantilever with a sharp tip is deflected by features on a sample surface, much like in a phonograph but on a much smaller scale. A laser beam reflects off the backside of the cantilever into a set of photodetectors, allowing the deflection to be measured and assembled into an image of the surface.

nanotechnology and which were results of nanotechnology research.

Nanoscience and nanotechnology only became possible in the 1910s with the development of the first tools to measure and make nanostructures. But the actual development started with the discovery of electrons and neutrons which showed scientists that matter can really exist on a much smaller scale than what we normally think of as small, and/or what they thought was possible at the time. It was at this time when curiosity for nanostructures had originated.

The atomic force microscope (AFM) and the Scanning Tunneling Microscope (STM) are two early versions of scanning probes that launched nanotechnology. There are other types of scanning probe microscopy, all flowing from the ideas of the scanning confocal microscope developed by Marvin Minsky in 1961 and the scanning acoustic microscope (SAM) developed by Calvin Quate and coworkers in the 1970s, that made it possible to see structures at the nanoscale. The tip of a scanning probe can also be used to manipulate nanostructures (a process called positional assembly). However, this is a very slow process. This led to the development of various techniques of nanolithography such as dip pen nanolithography, electron beam lithography or nanoimprint lithography. Lithography is a top-down fabrication technique where a bulk material is reduced in size to nanoscale pattern.

The top-down approach anticipates nanodevices that must be built piece by piece in stages, much as manufactured items are currently made. Scanning probe microscopy is an important technique both for characterization and synthesis of nanomaterials. Atomic force microscopes and scanning tunneling microscopes can be used to look at surfaces and to move atoms around. By designing different tips for these microscopes, they can be used for carving out structures on surfaces and to help guide self-assembling structures. Atoms can be moved around on a surface with scanning probe microscopy techniques, but it is cumbersome, expensive and very time-consuming. For these reasons, it is not feasible to construct nanoscaled devices atom by atom. Assembling a billion transistor microchips at the rate of about one transistor an hour is inefficient.

In contrast, bottom-up techniques build or grow larger structures atom by atom or molecule by molecule. These techniques include chemical synthesis, self-assembly and positional assembly. Another variation of the bottom-up approach is molecular beam epitaxy or MBE. Researchers at Bell Telephone Laboratories like John R. Arthur. Alfred Y. Cho, and Art C. Gossard developed and implemented MBE as a research tool in the late 1960s and 1970s. Samples made by MBE were key to to the discovery of the fractional quantum Hall effect for which the 1998 Nobel Prize in Physics was awarded. MBE allows scientists to lay down atomically-precise layers of atoms and, in the process, build up complex structures. Important for research on semiconductors, MBE is also widely used to make samples and devices for the newly emerging field of spintronics.

Newer techniques such as Dual Polarisation Interferometry are enabling scientists to measure quantitatively the molecular interactions that take place at the nano-scale.

Applications

Although there has been much hype about the potential applications of nanotechnology, most current commercialized applications are limited to the use of "first generation" passive nanomaterials. These include titanium dioxide nanoparticles in sunscreen, cosmetics and some food products; silver nanoparticles in food packaging, clothing, disinfectants and household appliances; zinc oxide nanoparticles in suncreens and cosmetics, surface coatings, paints and outdoor furniture varnishes; and cerium oxide nanoparticles as a fuel catalyst. The Woodrow Wilson Center for International Scholars' Project on Emerging Nanotechnologies hosts an inventory of consumer products which now contain nanomaterials.

However further applications which require actual manipulation or arrangement of nanoscale components await further research. Though technologies currently branded with the term 'nano' are sometimes little related to and fall far short of the most ambitious and transformative technological goals of the sort in molecular manufacturing proposals, the term still connotes such ideas. Thus there may be a danger that a "nano bubble" will form, or is forming already, from the use of the term by scientists and entrepreneurs to garner funding, regardless of interest in the transformative possibilities of more ambitious and far-sighted work.

The National Science Foundation (a major source of funding for nanotechnology in the United States) funded researcher David Berube to study the field of nanotechnology. His findings are published in the monograph "Nano-Hype: The Truth Behind the Nanotechnology Buzz". This published study (with a foreword by Mihail Roco, head of the NNI) concludes that much of what is sold as "nanotechnology" is in fact a recasting of straightforward materials science, which is leading to a "nanotech industry built solely on selling nanotubes, nanowires, and the like" which will "end up with a few suppliers selling low margin products in huge volumes."

Implications

Due to the far-ranging claims that have been made about potential applications of nanotechnology, a number of concerns have been raised about what effects these will have on our society if realized, and what action if any is appropriate to mitigate these risks. Short-term issues include the effects that widespread use of nanomaterials would have on human health and the environment. Longer-term concerns center on the implications that new technologies will have for society at large, and whether these could possibly lead to either a post scarcity economy, or alternatively exacerbate the wealth gap between developed and developing nations.

Health and environmental issues

There is a growing body of scientific evidence which demonstrates the potential for some nanomaterials to be toxic to humans or the environment [3], [4], [5]. The smaller a particle, the greater its surface area to volume ratio and the higher its chemical reactivity and biological activity. The greater chemical reactivity of nanomaterials results in increased production of reactive oxygen species (ROS), including

free radicals [6]. ROS production has been found in a diverse range of nanomaterials including carbon fullerenes, carbon nanotubes and nanoparticle metal oxides. ROS and free radical production is one of the primary mechanisms of nanoparticle toxicity; it may result in oxidative stress, inflammation, and consequent damage to proteins, membranes and DNA [7].

The extremely small size of nanomaterials also means that they are much more readily taken up by the human body than larger sized particles. Nanomaterials are able to cross biological membranes and access cells, tissues and organs that larger-sized particles normally cannot [8]. Nanomaterials can gain access to the blood stream following inhalation [9] or ingestion [10]. At least some nanomaterials can penetrate the skin [11]; even larger microparticles may penetrate skin when it is flexed [12]. Broken skin is an ineffective particle barrier [13], suggesting that acne, eczema, shaving wounds or severe sunburn may enable skin uptake of nanomaterials more readily. Once in the blood stream, nanomaterials can be transported around the body and are taken up by organs and tissues including the brain, heart, liver, kidneys, spleen, bone marrow and nervous system [14]. Nanomaterials have proved toxic to human tissue and cell cultures, resulting in increased oxidative stress, inflammatory cytokine production and cell death [15]. Unlike larger particles, nanomaterials may be taken up by cell mitochondria [16] and the cell nucleus [17], [18]. Studies demonstrate the potential for nanomaterials to cause DNA mutation [19] and induce major structural damage to mitochondria, even resulting in cell death [20], [21].

Size is therefore a key factor in determining the potential toxicity of a particle. However it is not the only important factor. Other properties of nanomaterials that influence toxicity include: chemical composition, shape, surface structure, surface charge, aggregation and solubility [22], and the presence or absence of "functional groups" of other chemicals [23]. The large number of variables influencing toxicity means that it is difficult to generalise about health risks associated with exposure to nanomaterials – each new nanomaterial must be assessed individually and all material properties must be taken into account.

In its seminal 2004 report Nanoscience and Nanotechnologies: Opportunities and Uncertainties, the United Kingdom's Royal Society recommended that nanomaterials be regulated as new chemicals, that research laboratories and factories treat nanomaterials "as if they were hazardous", that release of nanomaterials into the environment be avoided as far as possible, and that products containing nanomaterials be subject to new safety testing requirements prior to their commercial release. Yet regulations world-wide still fail to distinguish between materials in their nanoscale and bulk form. This means that nanomaterials remain effectively unregulated; there is no regulatory requirement for nanomaterials to face new health and safety testing or environmental impact assessment prior to their use in commercial products, if these materials have already been approved in bulk form.

The health risks of nanomaterials are of particular concern for workers who may face occupational exposure to nanomaterials at higher levels, and on a more routine basis, than the general public.

Broader societal implications and challenges

Beyond the toxicity risks to human health and the environment which are associated with first-generation nanomaterials, nanotechnology has broader societal implications and poses broader social challenges. Social scientists have suggested that nanotechnology's social issues should be understood and assessed not simply as "downstream" risks or impacts, but as challenges to be factored into "upstream" research and decision making, in order to ensure technology development that meets social objectives [24]. Many social scientists and civil society organisations further suggest that technology

assessment and governance should also involve public participation [25], [26], [27], [28].

Some observers suggest that nanotechnology will build incrementally, as did the 18-19th century industrial revolution, until it gathers pace to drive a nanotechnological revolution that will radically reshape our economies, our labour markets, international trade, international relations, social structures, civil liberties, our relationship with the natural world and even what we understand to be human. Others suggest that it may be more accurate to describe nanotechnology-driven changes as a "technological tsunami". Just like a tsunami, analysts warn that rapid nanotechnology-driven change will necessarily have profound disruptive impacts. As the APEC Center for Technology Foresight observes:

> If nanotechnology is going to revolutionise manufacturing, health care, energy supply, communications and probably defence, then it will transform labour and the workplace, the medical system, the transportation and power infrastructures and the military. None of these latter will be changed without significant social disruption. [29]

The implications of the analysis of such a powerful new technology remain sharply divided. Nano optimists, including many governments, see nanotechnology delivering environmentally benign material abundance for all by providing universal clean water supplies; atomically engineered food and crops resulting in greater agricultural productivity with less labour requirements; nutritionally enhanced interactive 'smart' foods; cheap and powerful energy generation; clean and highly efficient manufacturing; radically improved formulation of drugs, diagnostics and organ replacement; much greater information storage and communication capacities; interactive 'smart' appliances; and increased human performance through convergent technologies [30], [31].

Nano sceptics suggest that nanotechnology will simply exacerbate problems stemming from existing socio-economic inequity and the unequal distribution of power by creating greater inequities between rich and poor through an inevitable nano-divide (the gap between those who control the new nanotechnologies and those whose products, services or labour are displaced by them); destabilising international relations through a growing nano arms race and increased potential for bioweaponry; providing the tools for ubiquitous surveillance, with significant implications for civil liberty; breaking down the barriers between life and non-life through nanobiotechnology, and redefining even what it means to be human [32], [33].

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See also

- List of nanotechnology topics
- Nanoengineering
- Nanotechnology in fiction
- Top-down and bottom-up design
- Nanotechnology education
- List of nanotechnology organizations
- Energy Applications of Nanotechnology
- Grinding and Dispersing Nanoparticles

Further reading

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External links

For external links to companies and institutions involved in nanotechnology, please see List of nanotechnology organizations.

- Nanotechnology at the Open Directory Project

- Nanotechnology NanoWiki - The nanotechology page of the Norwegian University of Science and Technology
- Nanotechnology Now - News and information source on everything nano
- Nanotechnology.com
- Small Times - Nanotechnology News & Resources
- nanoHUB - Online Nanotechnology resource with simulation programs, seminars and lectures
- Nanowerk Nanotechnology Portal

- European Nanoforum
- NanoEd Resource Portal - Repository of courses, concepts, simulations, professional development programs, seminars, etc.
- National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT)
- NanoHive@Home - Distributed Computing Project
- American Association for Cancer Research: Nanotechnology
- Capitalizing on Nanotechnolgy's Enormous Promise - Article from CheResources.com
- RARE Corporation Nanotechnology professional development short courses
- Manufacturing Engineering Centre (MEC), Cardiff University, UK.
- VIDEO: Using Nanotechnology to Improve Health in Developing Countries February 27, 2007 at the Woodrow Wilson Center

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